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Processing Efficiency in Mental Tasks in Relation to Working Times

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Introduction

Research on time aspects of work behaviour is not very popular in modern work psychology. The exception might be the research on irregular working hours and/or shiftwork. A minor part of this research, however, is devoted to the study of work performance. Our knowledge of the effects on work performance of the various aspects of working times, like the length, the intensity and the scheduling of rest pauses, is predominantly based on studies of manual production work. And the majority of these studies was done more than fifty years ago. During and after WO-I, the Industrial Fatigue Research Board in England carried out many investigations on the effects on performance in repetitive perceptual-motor tasks of the varying length of the working day and/or working week, and of the scheduling of pauses (eg. Vernon, 1921; Wyatt, 1927). Similar studies have been done during that time in Germany (eg. Graf, 1922 and 1926) and in the US (eg. National Industrial Conference Board, 1920; Sargant Florence, 1924). In general, the results of these studies advocated an optimal length of the working week, 48 hours, and of the working day, 8 to 9 hours, and the periodic scheduling of short rest pauses during the working day. Both the production and the absenteeism, as well as the workers' well-being should profit from such optimal scheduling of the working times. These conclusions have been supported afterwards, in a large scale study sponsored during and after WO-II by the US Department of Labor (Kossoris, 1944; Kossoris & Kohler, 1947).

During the last decades, however, the character of work has changed, from the manipulation of tangible objects to the mental processing of abstract data. Accordingly, the general character of the workload has changed, from predominantly physical-energetical to mental. Moreover, the organization of working tasks has changed in modern labor, and in particular their structuring in time. Therefore, the investigation of the effects of working times on mental performance is valid for theoretical and for practical reasons. Such studies may provide insights in the impact of fatigue on mental performance, and its eventual effects on well-being and health. This research may also be relevant in practical discussions on the acceptability of shift length in modern information work, on the scheduling of rest pauses and on the optimal length of recuperation time after periods of intensive mental activities.

Purpose

In this contribution, effects of various aspects of the working times on mental task performance will be addressed. Such effects will be discussed in relation to the length, the intensity, and the irregularity of working times. Several field studies will be described. In all these studies a standard memory search task was used in a so-called interpolation paradigm, during or after the natural work routine. The effects of the various time aspects of the natural work routine on the information processing efficiency in this mental task were the object of investigation.

Theory and methods

Mental fatigue as a change of processing efficiency

Our main concern in this contribution pertains to the effects of working time aspects on the deterioration of mental capacity or on mental fatigue. Mental fatigue, however, is a rather complicated concept, and we may even wonder if it exists as a sound psychological concept (Meijman, 1991). A valuable approach may be the study of the changing relation between the formal output-aspects of the (mental) performance itself, such as its quantity (or speed) and/or its quality (or accuracy), and the (mental) resource mobilization which was actually needed in order to realize that performance. Such costs (needed mobilization of resources) and benefits (quantity and/or quality of performance) trade-offs may provide insights in the work-efficiency of the information processing system. Mental fatigue may be used as the term describing the phenomenon of a gradually changing efficiency of the human information processing system, as a result of its continuous use during preceding activities.

This approach of mental fatigue is connected to cognitive-energetic models of mental task performance (Sanders, 1983; Mulder, 1986; Hockey, 1986 and 1993), or to theories on the regulation of mental effort. According to these theories, mental effort is a compensatory process of cognitive-energetical control mechanisms in the management of mental task demands. By means of such self-regulating mechanisms mental task performance is protected against a deterioration of capacity, which may be provoked by the length and/or the intensity of preceding work activities, or which may be the result of working and resting during less optimal circadian phases as will be the case in night work.

It was Edward Thorndike (1900 and 1912) in his discussion with Kraepelins' "curve of work method" (1897), who formulated for the first time in history a theory on the compensatory character of effort in mental task performance. He pointed out that it is highly implausible for mental fatigue to show up as performance impairment as long as the subject is willingly to compensate by investing more effort. Following the ideas of Dodge (1913) on the so-called psychodynamics of mental work, Thorndike (1914) proposed an efficiency paradigm in the study of mental fatigue. He advocated that the performance in mental tasks must always be related to some parameter of the costs involved in the realization of that performance. To this end he recommended (psycho)physiological indicators. This efficiency paradigm in the study of mental task performance has been largely forgotten[1] until the seventies and the eighties, when the interest of mental performance researchers turned to the energetical aspects of cognitive functioning (eg Kahneman, 1973; Navon & Gopher, 1979; Sanders, 1983; Schönpflug, 1983; Hockey et al., 1986; Heemstra, 1988).

The measurement of mental effort

Indicators of mental effort, as a compensatory process, can be derived from changes in the sympathetic-parasympathetic balance, resulting from the organisms' attempts to adapt to environmental demands. Such changes are supposed to be related to arousal mechanisms in the regulation of mental activity. Heart rate variability or parameters derived from it, such as the 0.10 Hz component in the power spectrum of this signal (G. Mulder, 1980; L.

[1]. An exception is the very interesting study by Tent (1962).

Mulder, 1988), have been frequently used to this end. This latter measure was used throughout all studies which will be reported in this contribution. At the recommendations of Vicente, Thornton and Moray (1987) it was adapted in order to standardize it over different subjects. Each subject's task value was subtracted from his value during a 3 minutes rest period preceding the task itself. This difference was then expressed in percentage of this rest value. The resulting score, which thus was standardized on each subject's personal variability, varies from 0 to 100. A higher score means 'more effort'.

The mental task used

The mental task under study is a simple memory search task, of a type as described by Massaro (1975) and Aasman, Mulder and Mulder (1987). Basically, the subject has to react, as quickly as possible, to a display set of characters that may or may not contain a character belonging to the so-called memory set which had to be memorized before the display set is presented. Several modifications of this basic paradigm are possible. 1) The taskload may be varied, from 1 character in both sets to 5 or even 6. Six or more characters, however, exceed the abilities of most subjects to perform the task. Commonly 4 characters are used. 2) The processing mode may be varied, from a consistent mapping mode to a varied mapping mode (Shiffrin and Schneider, 1977). In the consistent mapping mode an automatic processing of information may develop after training, meaning that the task performance is then hardly attention demanding. In the varied mapping mode automatic processing is impossible, meaning that the task performance is always attention demanding. 3) The task difficulty can be increased by an additional instruction of storing into memory of the number of presentations of each character of the memory set in a series of 40 to 50 presentations of the display set: the so-called counting instruction.
In the studies which will be described, the task is used in various modalities.

Length of working time

In a study of 18 city bus drivers, men between 30 and 40 years of age (Mulders, Meijman, Kompier, Mulder, Broersen, Westerink and O'Hanlon, 1988), the effects of the length of the preceding working time on processing efficiency were investigated. The drivers performed the memory search task in four different conditions, each time at 13:00 in the afternoon. The first condition was a day-off (referred to as condition F); the second condition was a late shift with working times from 14:30 until 23:30 (referred to as condition L); the third condition was a day-shift with working times from 9:00 until 16:30 (referred to as condition D); and the fourth condition was a morning shift with working times from 5:30 to 13:00 (referred to as condition M). The order of the conditions was balanced over the subjects; in between successive conditions were at least four other (working and/or free) days. The drivers worked always on the same bus line. Before performing the standard task the drivers had been engaged in their normal daily work routine during condition D for 4 hours and during condition M for 7.5 hours. In the conditions L and F they had not been engaged in work routines of the driving job.

In Figure 1 the results are presented with respect to the memory search task in the varied mapping mode with 4 characters in the memory- and the display set, without the counting instruction, task 4D. The indicator of mental effort is on the Y-axis, and reaction time (correct yes-responses) is on the X-axis.

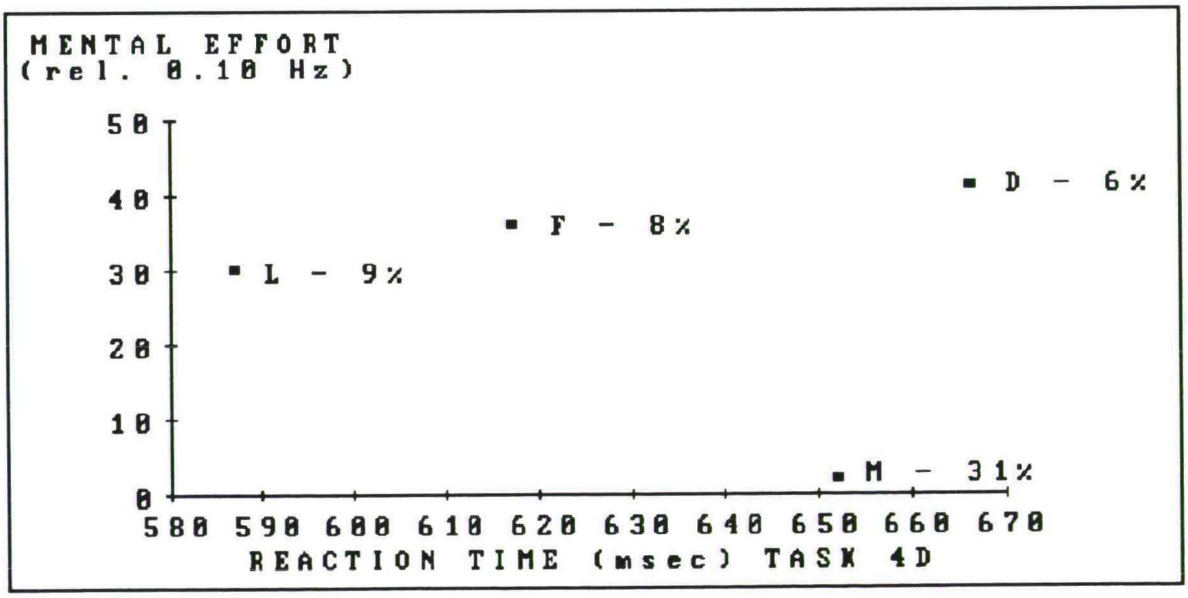

FIGURE 1: Reaction time and effort of 18 busdrivers in a memory search task, after 0 hours of work (F and L), 4 hours of work (D) and 8 hours of work (M).

It can be seen in Figure 1 that the drivers realize a mean reaction time in condition F of 617 msec at the cost of a mean effort score of 36. In the other condition without preceding work, condition L, they react more quickly (mean 587 msec), though statistically not significant, at approximately the same level of costs (mean effort score 30). After 4 hours of work, in condition D, their reaction time is, statistically significant, longer (mean 666 msec) at even slightly higher costs (mean effort score 41). After 7.5 hours of work, in condition M, a surprising result is observed. The reaction time is more or less equal to the performance in condition D (mean 652 msec), but the effort score is very low (mean score 2). In Figure 1 the percentages of the 'missing'-responses are also presented. In the three conditions L, F and D these percentages are rather low, respectively 9%, 8% and 6%. In condition M the drivers do not react to 31% of the signals, meaning they did not pay serious attention to the task.

This study shows that changes in processing efficiency in memory search can be observed in relation to the length of preceding work activities. After 4 hours of work the drivers invest approximately the same amount of effort in the task, but they pay the price of a slower reaction. After 8 hours of work, most probably combined with some sleep deprivation due to an early morning rise, they are unwillingly to pay attention to the task. Such strategic change in mental task performance may be interpreted as a serious indication of (mental) fatigue (Holding, 1983; Meijman, 1991).

From the available research on the effects of long working shifts, mostly comparisons between 8-hour and 12-hour rotating shifts, no definite conclusions can be drawn with respect to performance impairments in mental tasks due to long working hours (for example: Alluisi and Morgan, 1982; Rosa, Colligan and Lewis, 1989; Daniel and Potasowa, 1989). It seems from such studies that sleepiness might be an important factor (Akerstedt, 1988 and 1991; Campbell, 1992). To our knowledge, in none of these studies an efficiency paradigm has been followed. Our results suggest that effects of the length of preceding working times, compared to non-loading base-line conditions, might be detected in memory search processes by not only studying the formal aspects of performance, but also the costs (effort) involved (Vries-Griever and Meijman, 1987).

Rest pauses

From the studies on perceptual motor tasks in production work it is well known that the lack of periodic short rest pauses during the working day may have detrimental effects on productivity (Alluisi and Morgan, 1982). Little is known, however, on the effects of short rest pauses during the working day on mental task performance. Such effects have been investigated in two studies.

The first study was done on 30 driving examiners, men with a mean age of 43 years (Meijman, Mulder, van Dormolen and Cremer, 1992). These examiners were studied in four conditions: a day-off, a working day with short breaks of 5 minutes between successive exams, a working day with short breaks of 2 minutes and a working day without any short breaks between successive exams. During all three working days the examiners had 30 minutes lunch pause, and 2 pauses of 15 minutes for coffee (in the morning) and tea (in the afternoon). All three working started at 8:00 and ended at 16:00. They differed with respect to the number of exams: 9 (the 5 minutes break day), 10 (the 2 minutes break day) and 11 (the day without any short break). At the end of the working days (16:30), and at the day-off also at 16:30, the examiners performed the memory search task. The order of the conditions was balanced over the subjects, and at least six days separated these conditions. In Figure 2 the results are presented with respect to the memory search task in the varied mapping mode, 4 characters in the memory- and the display set, without the additional counting instruction, task 4D. The mean reaction times (correct yes-responses) are displayed on the X-axis, and the mean effort scores (standardized 0.10 Hz component) on the Y-axis.

In the condition day-off ('Free' in Figure 2), without any preceding examining activities, the examiners realize a mean reaction time of 613 msec in the memory search task, at the cost of a mean effort score of 37. At the end of the working day with short breaks of 5 minutes the processing efficiency has changed: the mean reaction time is less as compared to the day-off (559 msec), but the costs are considerably and statistical significant higher (mean effort score is 57). At the end of the working day with short breaks of 2 minutes the mean reaction time is equal to the day-off (mean 611 msec), but the costs are higher (mean effort score 52). At the end of the working day without any short breaks, the processing efficiency is even more deteriorated. The mean reaction time is statistically significant deviating from the other conditions (mean 650 msec), and the costs are equal, or at least statistical not significantly deviating from the other working conditions but higher compared to the day-off condition (mean effort score 46). No differences were observed between the four conditions with respect to the 'missing'-percentages. Similar results were found with respect to the memory search task in the consistent mapping mode, 4 characters, but with the counting

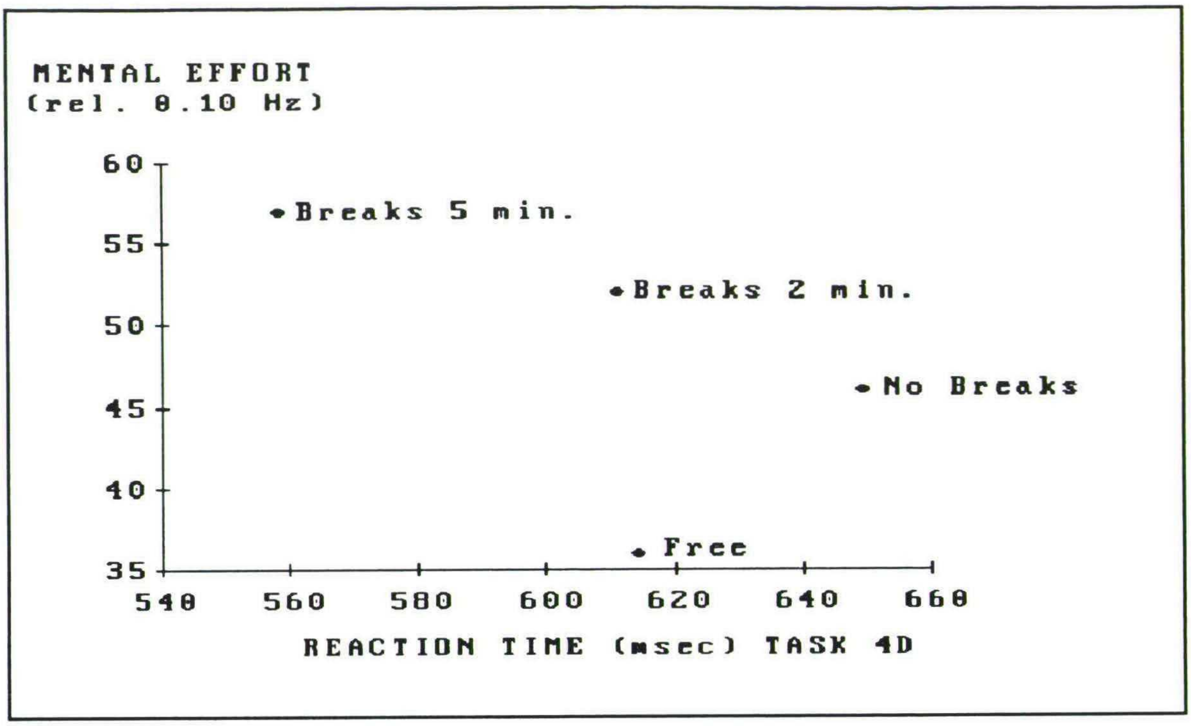

FIGURE 2: Mean reaction time and effort score of 27 driving examiners in a memory search task, performed under different regimes of short breaks during work. Task 4D.

instruction, Task DT. These data are presented in Figure 3.

In the condition day-off ('Free' in Figure 3) the examiners realize in this task, which is much more difficult than task 4D, a mean reaction time of 881 msec, at the cost of a mean effort score of 38. At the end of the working day with short breaks of 5 minutes the processing efficiency has remained more or less the same: the mean reaction time is 895 msec and the mean effort score is 43. At the end of the working day with short breaks of 2 minutes the mean reaction time is slightly, though statistically not significant impaired (mean reaction time 941 msec) and the costs are about the same (mean effort score 37). At the end of the working day without any short breaks, the processing efficiency is clearly deteriorated. The mean reaction time is statistically significant deviating from the other conditions (mean 1003 msec), and the costs are higher (mean effort score 52). No differences were observed between the four conditions with respect to the 'missing'-percentages.

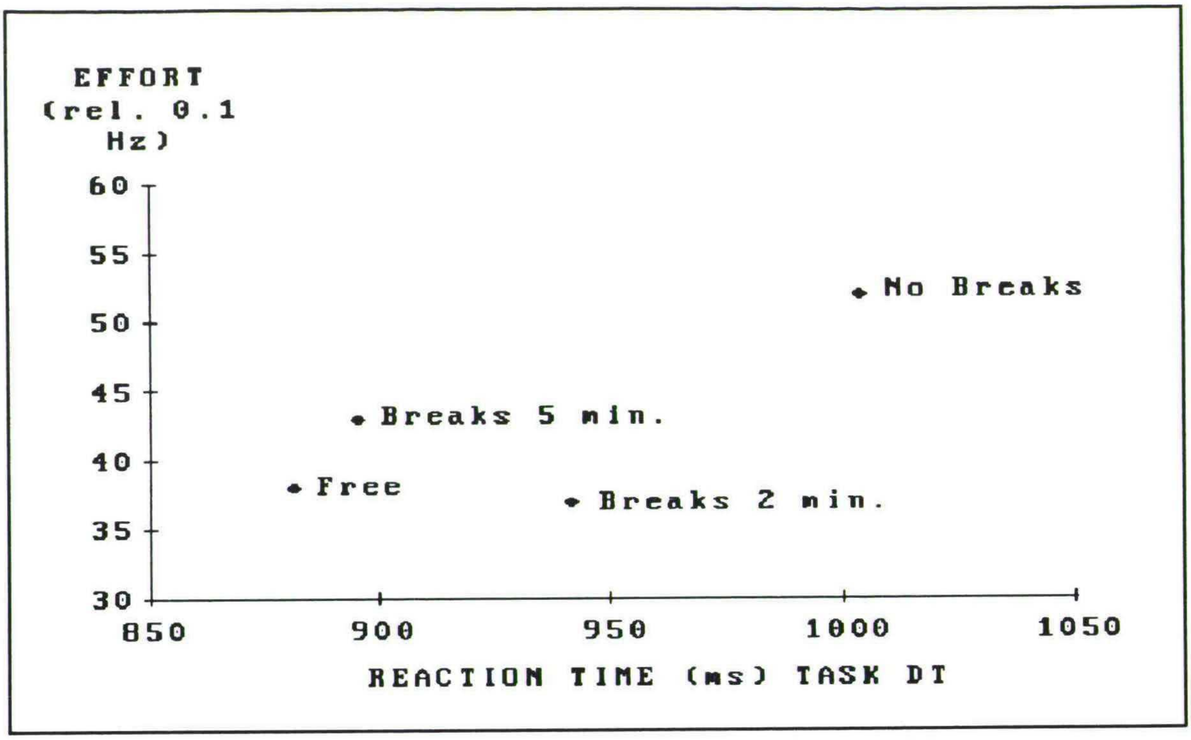

FIGURE 3: Mean reaction time and effort score of 27 driving examiners in a memory search task, performed under different regimes of short breaks during work. Task DT.

In a study by van Ouwerkerk (1989) similar results were found. Five administrative workers, men with a mean age of 36 years, were studied in three conditions. During a day-off at 16:30, without preceding working activities, they performed the memory search task (4 characters, consistent mapping, counting instruction), task DT. They performed the task also, at the same time, after a working day during which the total amount of work was equally spaced into four parts with a break of circa 10 minutes between part one and part two, a break of 30 minutes between part two and part three, and again a break of 10 minutes between part three and part four. This condition is referred to in Figure 4 as EDW. In the other condition, referred to as UW, they performed the task at 16:30 after a working day which was not spaced in equal work load periods and without the short intermittent breaks of 10 minutes.

Due to the small number of subjects no statistical significant differences were found. However, the results point into the same direction as the examiners study. At the end of the

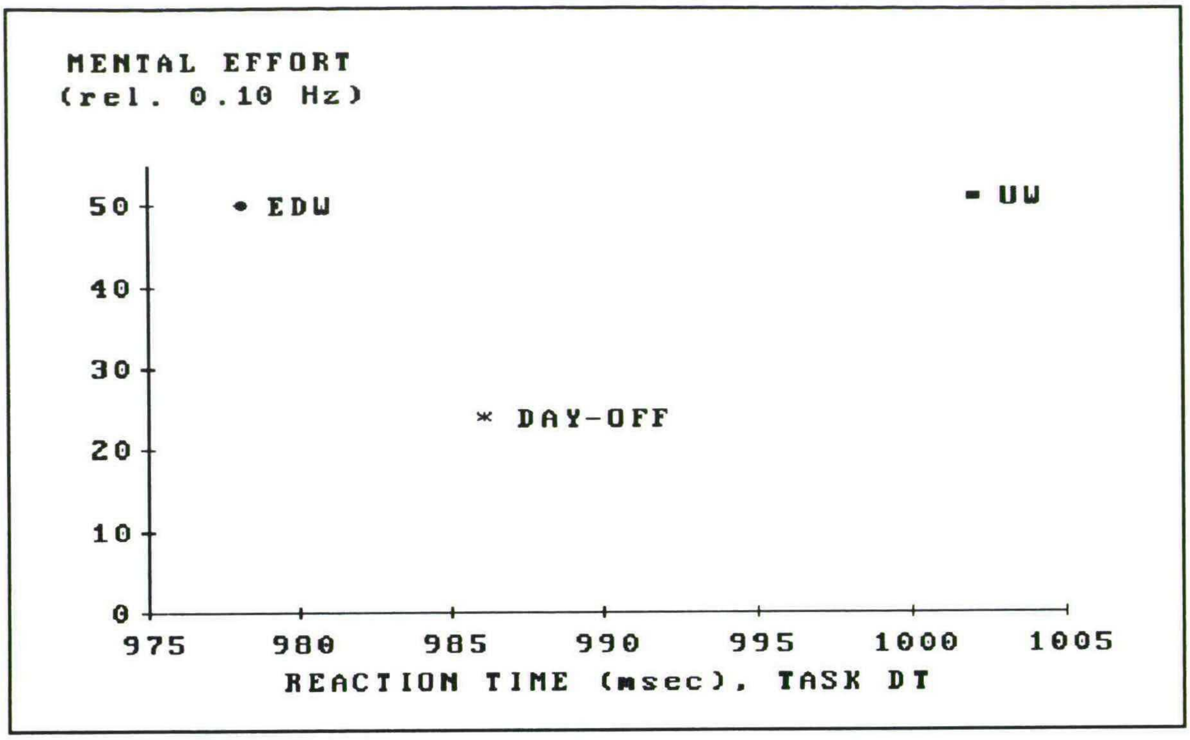

FIGURE 4: Mean reaction time and mean effort score in a memory search task of five administrative workers under different working conditions. Task DT.

day-off the administrative workers realized a mean reaction time of 986 msec at the cost of a mean effort score of 24. After the equally spaced working day with short breaks, they perform equally well (mean reaction time 978 msec), but at a higher cost (mean effort score 50). After the unorganized working day, without intermittent breaks, they perform worse (mean reaction time 1002 msec), at an equal level of costs compared to the other working day and a higher level compared to the day-off (mean effort score 51). No differences were observed with respect to the 'missing' percentages.

It can be concluded from these studies, that basic mechanisms in the processing of information might be affected by the intensity of the preceding work load. Such effects could most clearly be detected by studying the relation of performance and effort investment. Confining the study to either the performance data or the effort data alone does not reveal all the differences which are observed by means of the processing efficiency paradigm. For example in the driving examiners study, task 4D, no differences were found with respect to reaction times between the conditions day-off and the 2 minutes break condition. However, from the combination with the effort data it can be concluded that the processing efficiency had changed in the latter condition.

After-effects of circadian disruptions

Circadian rhythms have been observed in mental task performance. Perceptual-motor tasks are mostly impaired in the latter part of the night, whereas performance in working memory tasks is not. Semantic memory tasks show a similar trend as perceptual motor tasks (Folkard and Monk, 1985). Performance speed in perceptual motor tasks is faster in the late afternoon, but at the cost of accuracy, and it seems that this change in speed/accuracy trade-off is not volitionally influenced (Smith, 1992). Most research with respect to diurnal variations in mental task performance is restricted to the working period itself. Little is known about possible after-effects during the period off-duty following serious circadian disruptions as in night shifts. Research on such carry-over effects may provide insights in the impact of fatigue.

In order to investigate possible carry-over effects due to circadian disturbances in mental performance we studied 28 experienced shift workers, men with a mean age of 32 years (Meijman, van der Meer and van Dormolen, 1993). Two groups performed the memory search task during the afternoon (15:00) of the first fully undisturbed day-off, either after four (the 4N group of 8 subjects) or after seven (the 7N group of 12 subjects) consecutive night shifts, i.e., 32 hours after the end of the night work period. The mental task performance in this so-called night-recovery conditions was compared in both groups to the performance on the same task, also at 15:00, during a baseline condition: i.e., the last day of a 3-days-off period after a period of afternoon shifts (65 hours after the work period). For control purposes a third group of 8 workers was studied, also at 15:00, during the same baseline condition and during the first fully undisturbed day-off after four consecutive morning or afternoon shifts (25 or 17 hours after the end of the work. This last group will be referred at as the 4D group. All workers were assigned to the same tasks in their normal work routine.

Because it was expected that subjects would be able to compensate for a general suboptimal state, eventually due to the prolonged night work period with its inherent circadian disruption, a momentary state-change was induced by means of a physical exhaustion test on a bicycle ergometer. The reasoning behind this manipulation was to require the subjects to tax all their available resources. Therefore, the subjects performed in both baseline and recovery conditions the memory search task before and after the bicycle ergometer test. The data in this study are the post-cycle values subtracted from the pre-cycle values. Both the reaction times and the 0.10 Hz component were measured, and the post-cycle values were subtracted from the pre-cycle values. The memory search task was presented in a varied mapping mode, 4 characters, without the counting instruction.

In this study the non-standardized values of the 0.10 Hz component were used, because every subjects' post-cycle value is subtracted from his pre-cycle value, and thus intersubject standardization according to the Vicente et al. procedure is less wanted. As, with respect to the non-standardized values of the 0.10 Hz component, a lower value of this parameter is indicative for mental effort investment, a negative post-cycle minus pre-cycle value means that the subject invested more effort during the task after the ergometer test compared to the task before the ergometer test. Also, a negative post-cycle minus pre-cycle value of the reaction time means that the subject reacted slower after the ergometer test. In figure 5 the results are presented.

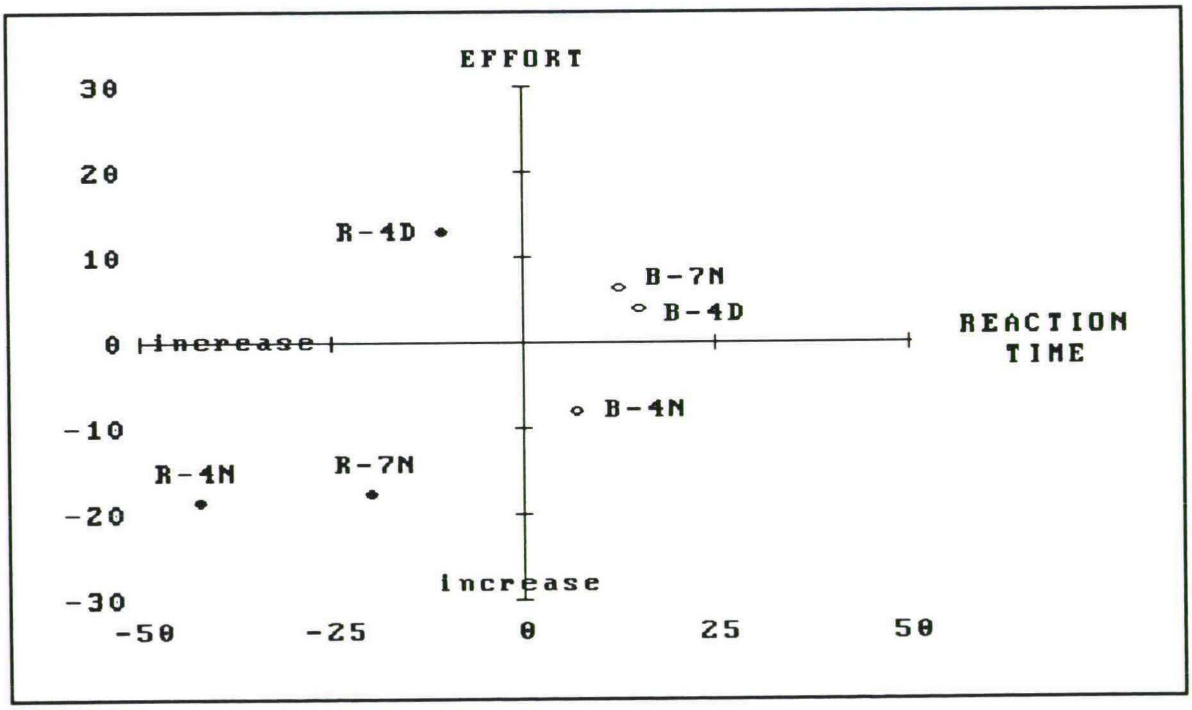

FIGURE 5: Mean reaction time and effort score (post-cycle minus pre-cycle values) in a memory search task, in baseline and in various recovery conditions.

In the baseline conditions no statistical significant differences between the three groups were found, neither with respect to the reaction time changes nor with respect to the changes in the effort measure. All three groups improved, though not statistical significant, their reaction times post-cycle compared to pre-cycle: the 4D group 15 msec (B-4D in figure 5), the 4N group 6.6 msec (B-4N) and the 7N group 12.5 msec (B-7N). With respect to the effort: both the 7N and the 4D group invested less effort post-cycle compared to pre-cycle: respective values 6.5 and 4. The 4N group invested more effort post-cycle compared to pre-cycle (mean score -8). However, these differences were not significant.

In the recovery condition both night work groups differed from the day work group. The reaction times of the 4N (mean -42.5 msec) and the 7N group (mean -20 msec) deteriorated post-cycle compared to pre-cycle, whereas the 4D group (mean -10.8 msec) deteriorated much less. This difference was statistically significant. The 4N and the 7N group invested more effort port-cycle compared to pre-cycle (mean -18.5 and -17.5), whereas the 4D group invested less effort post-cycle compared to pre-cycle (mean 13). This difference was, marginally, significant.

It might be concluded that the physical exercise during cycling affected the performance and the effort investment on the memory search task in the recovery conditions, but not in the baseline condition. These effects must be attributed to the burden of the preceding night work, and not to preceding day work. Despite the longer recovery time of the two night groups (32 hours) compared to the day group (17-25 hours), the performances of both night groups deteriorated more in the pre-cycle versus post-cycle comparison during the recovery day. The effort index was also affected in the same direction. In the baseline condition no differences were found between the three groups.

Conclusion

The results of the various studies reported in this contribution warrant serious attention to the effects of working time on mental task performance. The paradigm of the changing processing efficiency may be very useful in such research. Not only may it help to clarify eventual effects in a more articulated way, it may also provide a basis for the study of effects on well-being and health due to prolonged mental work under suboptimal conditions such as long work days, few rest pauses and night work. Depending on the stringency of norms with respect to the quality and the quantity of the performance in daily work routines, people defend their performance against impairment due to a deteriorated capacity by investing more effort. Prolonged mental effort investment may affect well-being and health by mechanisms of sustained activation of physiological systems which also play an important role in the stressreaction, in particular neuroendocrine reactions.

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